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THE MAUNA LOA HIGH-ALTITUDE OBSERVATORY

SAUL PRICE

U.S. Weather Bureau, Honolulu, Hawaii

and

JACK C. PALES

U.S. Weather Bureau, Mauna Loa Observatory, Hawaii

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ABSTRACT

A description is given of the physical setting, facilities, and current program of Mauna Loa Observatory in Hawaii, with emphasis on its suitability as a site for field studies on a wide variety of phenomena.

1. INTRODUCTION

The new high-altitude observatory established in July 1956 at an elevation of 11,150 feet on the slopes of Mauna Loa, in the Hawaiian Islands, has already been described by Fox [2,3]. The purpose of the present paper is to review the observatory's first 2 years and to consider in somewhat greater detail the climatic environment and such aspects of the physical setting, facilities, and programs most likely to interest those concerned with the possible suitability of such a mountain station for the study of specific phenomena within and outside the atmosphere.

Mauna Loa (Great Mountain) is situated on the island of Hawaii, largest and southernmost of the Hawaiian group (fig. 1). To the north it faces its sister peak, Mauna Kea, across a 6,000-foot saddle. To the east, west, and south it falls gently to the sea from its 13,680-foot summit, comprising thereby more than half the entire island (fig. 2). Measured from its roots on the ocean floor 18,000 feet below sea level, Mauna Loa is the earth's greatest single mountain mass. About 128 square miles of its surface lie above 10,000 feet.

Geologically, Hawaii is the youngest of the Hawaiian Islands. It is, in fact, still being formed [17]—a process to which Mauna Loa itself contributes by erupting every few years. Consequently, its slopes have not been eroded into the deep valleys and sharp ridges of the older, more northerly islands, but retain the smooth and gradual symmetry (the average grade is 7 percent) of the fresh volcanic cone (fig. 3). The lower slopes are regions of heavier rainfall and are densely vegetated; higher elevations are virtually barren wastes of dark lava.

At about 19°30′ N. latitude, Mauna Loa is well within the geographic Tropics. A solitary peak, except for Mauna Kea, and more than 2,000 miles from the nearest continental land mass, it lies in the midst of a tropical ocean which, in that vicinity, has a mean annual temperature of 75° F., an annual range of 5° F., and a daily range of less than 2° F.

The prevailing surface wind in this locality, south and west of the eastern Pacific high pressure cell, is the northeasterly trade, which has a frequency of 90 percent in summer and 80 percent for the year as a whole. Also characteristic of the region, and occurring with nearly the same frequency, is the trade inversion, whose average height of approximately 6,500 feet is only half that of Mauna Loa itself and corresponds to the mean timberline on its slopes.

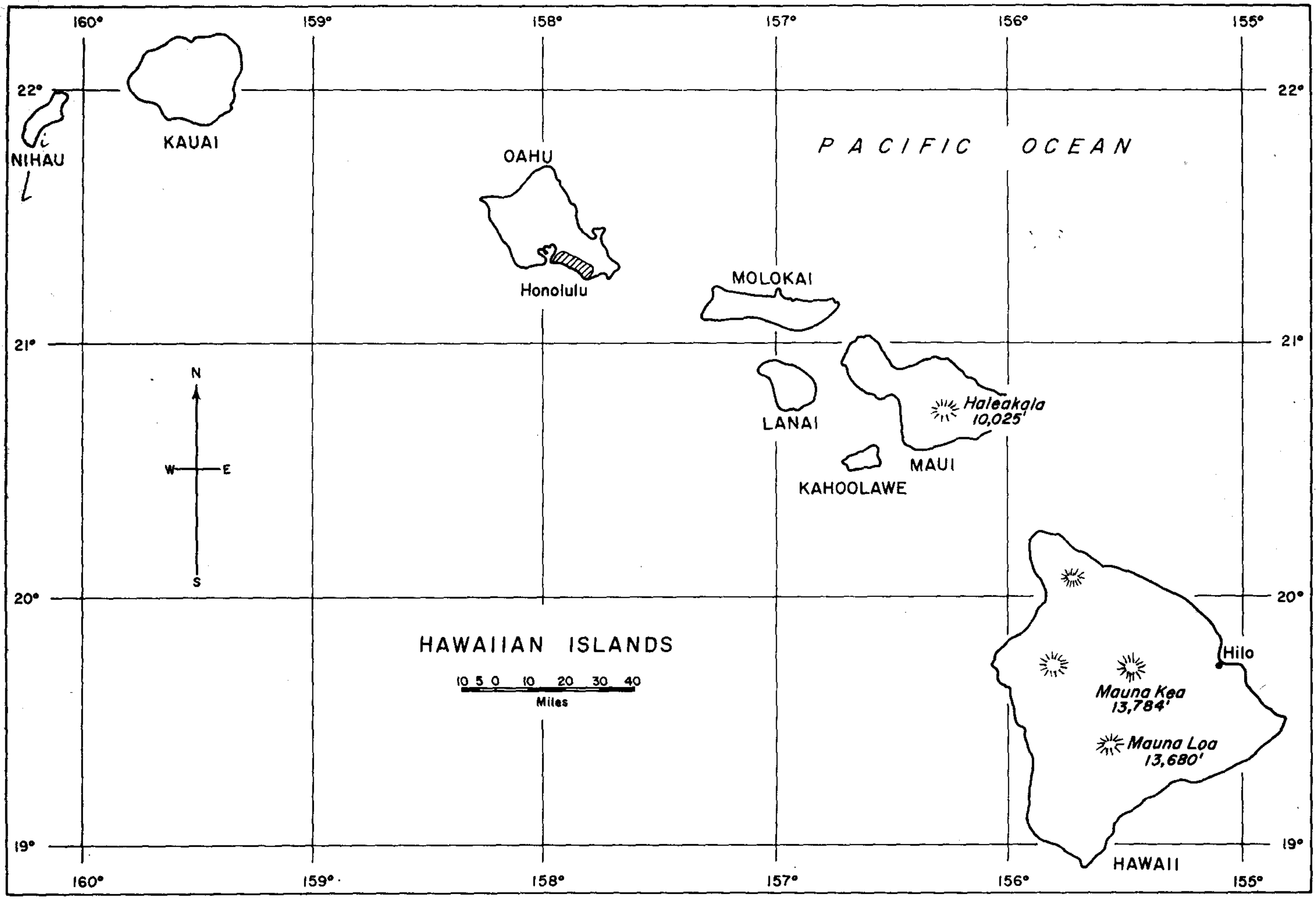

FIGURE 1.—The Hawaiian Islands.

2. HISTORY

The potential value of a high-altitude geophysical observatory in the oceanic Tropics had long been realized. The uniqueness of Mauna Loa in this respect—conferred by its height, insularity, mildness of climate at all elevations, distance from sources of industrial pollution, yet accessibility from large cities, freedom (due to the trade inversion) from most of the water vapor and debris of the lower atmosphere, and by the climatic uniformity of the maritime tropical environment—was given early recognition by the First Pan Pacific Science Congress which, meeting in Honolulu in 1921, adopted a resolution calling for the establishment of a weather station at the summit. But it was not until 1950 that the laying down across the lava wastes of a cinder road traversable by motor vehicles made the upper reaches of the mountain readily accessible and an observing station there feasible.

In December 1951, a small masonry hut was constructed at an elevation of 13,400 feet—one-fourth mile from, and 280 feet below, the summit. This was designed to house 90-day weight-driven recorders for atmospheric pressure, temperature, relative humidity, wind, sunshine, and precipitation, and to provide temporary shelter for scientific parties (fig. 4). Building and equipment were admittedly crude, and were regarded only as a first step toward the realization of a manned mountain observatory.

At the same time, rain gages and instrument shelters containing conventional barographs, hygrothermographs, and thermometers were placed along the slope at elevations of 5,100, 8,300, and 11,500 feet and, together with the summit station, were visited at intervals by employees of the U.S. Weather Bureau Office at Hilo, Hawaii. From the accumulating records, the first quantitative portrait of the climate of the upper mountain began to emerge [12].

In June 1956, in cooperation with the National Bureau of Standards, the Weather Bureau erected at 11,150 feet a much larger structure intended to provide working facilities and living quarters for extended stays by scientific parties or for a permanent staff. This was named the Slope Unit of the Mauna Loa Observatory, and will be referred to in what follows as the Mauna Loa Observatory or simply as the Observatory. With the assignment to Mauna Loa of an important role in the International Geophysical Year (IGY) [4] a permanent staff of three Weather Bureau employees was appointed in July 1957 to conduct its programs of meteorological and other geophysical observations.

3. OBSERVATORY SITE

Altitude: 11,150 feet (3,398 meters)
Latitude: 19°32′ N.
Longitude: 155°35′ W.
Geomagnetic latitude: 19.9° N.

The Observatory lies within a leveled 4.05-acre plot on the gently sloping north-northeast face of Mauna Loa. On every side stretches the vast barren sea of dark aa lava,[1] loosely heaped and crumbling, which composes the mantle of the upper mountain, with here and there smaller patches of pahoehoe,[1] like pools of congealed molasses (fig. 5).

4. ACCESSIBILITY

From Hilo, the largest city (population 25,000) on the island of Hawaii, the Observatory is a 2-hour drive over 45 miles of crushed lava road. Honolulu, a modern American city of 300,000 and the cultural, economic, and population center of the Hawaiian Islands, with research institutes, technical libraries, and a large university, is only an hour and a quarter distant by air, with frequent daily commercial flights.

[1] The Hawaiian terms for the local lavas have entered into the vocabulary of volcanology. Aa resembles loosely strewn rubble; pahoehoe is billowy or ropy and, because it is often relatively unbroken, much more highly reflective than aa. Both are basic and have the same composition in the molten state. Differences arise during cooling, the aa forming at lower temperatures, smaller gas content, and more advanced crystallization. See Gordon A. MacDonald, "Pahoehoe, Aa, and Block Lava," *American Journal of Science*, vol. 251, Mar. 1951, pp. 169–191.

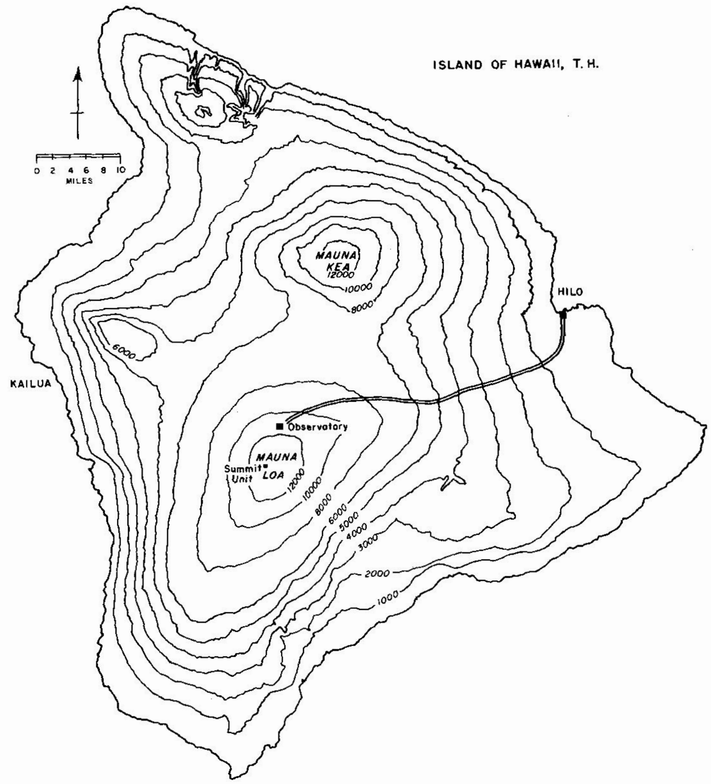

FIGURE 2.—Topographic map of Hawaii showing the Slope and Summit Units of the Mauna Loa Observatory, and the road from Hilo.

The road up Mauna Loa gradually ascends the northeast face of the mountain, through a luxuriant tropical rain forest of epiphyte-covered trees, ferns, and sedge flourishing upon the lava. Along the route the average rainfall

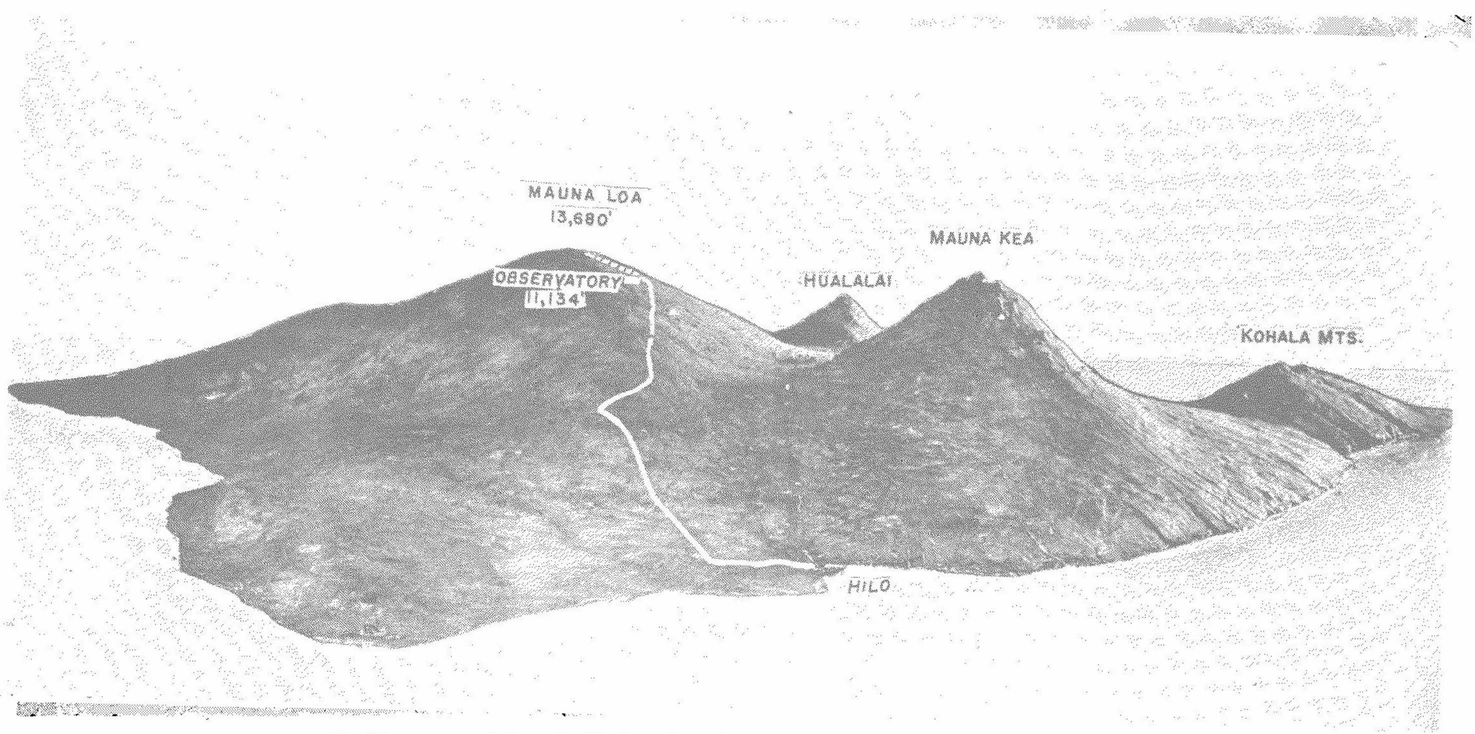

FIGURE 3.—Hawaii, photographed from a model at the University of Hawaii, and showing the smooth slopes, gentle gradients, and symmetry of Mauna Loa. Vertical exaggeration, 2.5 times.

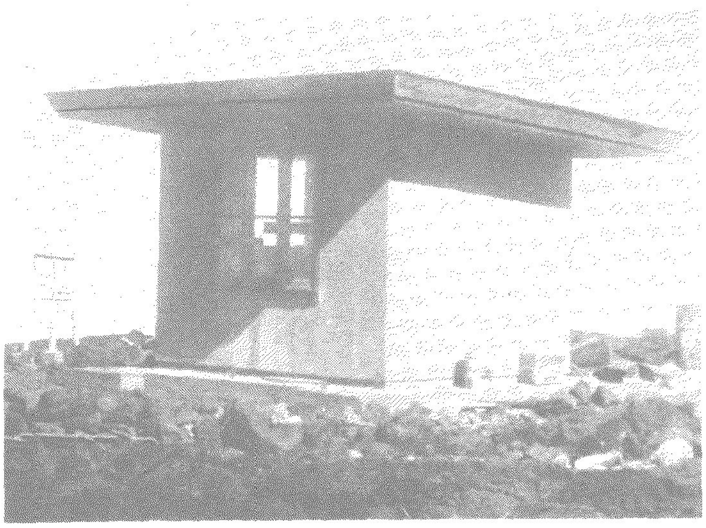

FIGURE 4.—Summit Unit, Mauna Loa Observatory. Elevation 13,400 feet (4,084 meters).

increases rapidly from 145 inches annually at Hilo to 250 inches between 2,500 and 3,000 feet (the island maximum exceeds 300 inches) and then decreases steadily to an estimated 15 inches at the summit. At about 6,000 feet the forest opens abruptly into fields of aa dotted with shrubs and scattered stands of trees. Soon these too grow sparse, and the road continues over a lava expanse broken only by gray patches of moss and lichens and an occasional shrub.

The road is maintained as a public highway by the Territory of Hawaii only to near the 6,000-foot level. Above that point, deterioration of the unconsolidated surface by weather and use presents a continuing problem, and a good paved road to the Observatory, and eventually to the summit itself, remains Mauna Loa's greatest present need. Still, except for short stretches where some difficulty in traction over the loose, hilly surface might be encountered, the road to the Observatory is negotiable by passenger car, with due caution against overheating and, possibly, carburetor adjustment with increasing altitude. However, a 4-wheel drive is preferable and, for the additional 8 miles to the summit, essential. For its own needs, the Observatory maintains two 4-wheel drive vehicles, one an open truck, the other an enclosed carryall. These make several round trips weekly and in rotation, leaving one vehicle always at the Observatory for emergency use.

FIGURE 5.—Aerial view of the Observatory, looking south (upslope), taken in bright sunlight. The very dark background is the aa lava which largely covers the upper mountain. Lighter patches are pahoehoe lava. The leveled 4.05-acre plot on which the Observatory stands is plainly visible. The road to the summit leads off to the right.

5. FACILITIES

The main building of the Observatory is a 20-by-40-foot concrete block structure, well insulated, and having a peaked roof of corrugated aluminum (fig. 6). It is partitioned internally into a comfortably furnished 16-by-20-foot living room-office (fig. 7), an instrument room, two bedrooms with accommodations for six, and a kitchen-dining room with propane hot water heater, cooking range, and refrigerator.

Along its south side is a concrete slab, 15 by 45 feet, for mounting instruments outdoors. Auxiliary structures include a wooden tower 8 by 8 feet with a platform 12.5 feet above the ground; the generator shed; the Dobson and various other instrument housings; fuel and water tanks; and the anemometer mast.

Electricity.—110-volt, single-phase, 60-cycle alternating current for household use and the scientific instruments is furnished by two recently installed 35 kw. diesel generators. These provide a more dependable source of electric power than that previously available, and are being operated alternately to permit preventive maintenance and thus insure against power interruptions. Since present use is approximately 10 kw., a substantial reserve remains to meet additional requirements. Three frequency regulators, with a total capacity of 600 watts, control the frequency to the more critical circuits and to the recorders.

Water is obtained by roof catchment drained into a 1,000-gallon tank and augmented, if necessary, by haulage from Hilo.

Workshop space is provided in the generator shed and in the enclosed base of the wooden tower. The Observatory is equipped with a small, but well-chosen, technical library, two desk calculators for data reduction, a microscope, the usual hand tools, a drill press, and a variety of electrical and electronic test instruments. Additional facilities for the purchase, fabrication, and repair of equipment are to be had in Hilo and Honolulu.

Communications.—50-watt transceivers at Mauna Loa maintain an open 24-hour radio contact with the Hilo Weather Bureau station, and the feasibility of a direct radio link with the Honolulu office, as well, is presently being explored. Mobile units identical to those at the

FIGURE 6.—The Mauna Loa Observatory, looking north. From left to right: (1) generator shed, (2) solar radiation instruments, (3) rain gages and instrument shelter, (4) diesel fuel tank, (5) anemometer mast, (6) water tank, (7) main building, (8) concrete apron, (9) Kiess-Corliss spectrograph shelter (see reference [6]), (10) Dobson spectrophotometer housing, (11) instrument platform, (12) fission products collector. In the background is Mauna Kea, about 25 miles distant. Intervening clouds are trade wind cumuli and lie over the saddle and below the level of the Observatory.

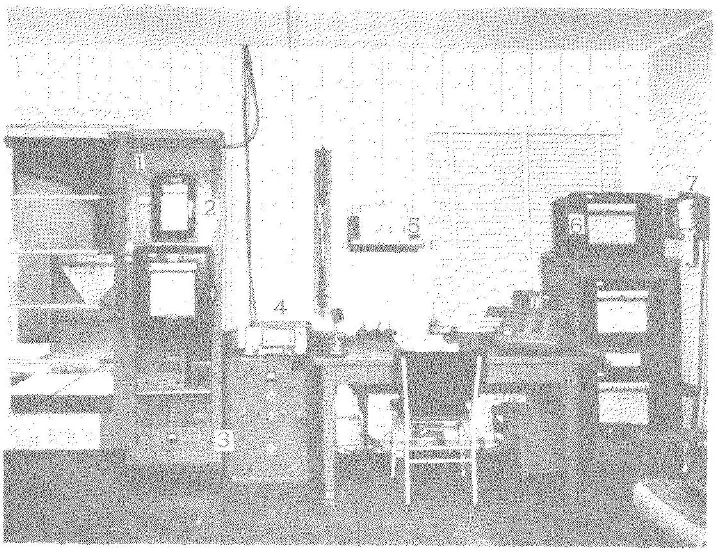

FIGURE 7.—Interior view of the Observatory's living room-office, south wall. (1) sunshine panel; (2) wind, sunshine, rainfall recorders; (3) frequency regulators; (4) 50-watt transceiver; (5) microbarograph; (6) from top to bottom, recorders for horizontal and normal incidence pyrheliometers, radiometer temperatures, and net exchange and total hemispherical radiometers; (7) recorder for surface ozone.

Observatory are mounted also in its vehicles. A powerful AM-FM-short wave receiver and a television set contribute to the recreation of staff and visitors. Reception is excellent.

6. STAFF

The Observatory's present complement includes the physicist-in-charge, two meteorological aides, and an electronics technician. Except for the latter, staff members spend 6 successive days on Mauna Loa and the seventh in Hilo, where those who are married maintain family residences. At least two persons remain on duty at the Observatory at any time. The principal responsibilities of the staff are to operate and service the scientific instruments, to take hourly weather observations, to reduce portions of the data, to cooperate in the projects of visiting scientists, and to do research.

Although visitors do occasionally experience some of the well-known discomforts of mountain sickness, the staff's acclimatization to the altitude has been complete and their general level of health excellent.

7. CLIMATE AND WEATHER

Unfortunately for so rich a subject, the scope of the present paper precludes more than a few remarks and some illustrative data concerning the weather and climate of the Observatory site. Additional information on the various and diverse climatic regimes of Mauna Loa, including its summit, is available in [12]. A fuller account is in preparation.

As might be anticipated from the tropical maritime locale, the Observatory's climate is comparatively mild for the altitude. Severe or violent weather is infrequent and the rigors of life at Alpine stations virtually unknown. On the contrary, the brilliant skies and intense insolation, the moderate temperature and low humidity, experienced in so bizarre and remote a setting, induce in most visitors feelings of exhilaration and well-being.

The Mountain circulation.—Like other mountains, Mauna Loa imposes upon the surrounding atmosphere a local circulation often remarkably indifferent to the large-scale movement of air in the region. This circulation has a complex origin, being due in part to mechanical interference by the mountain with the otherwise free flow of air in its vicinity, in part to differential heating and cooling of its slopes relative to one another and to the free air, and in part to pressure gradients set up by temperature differences at similar altitudes between the atmospheric strata overlying the mountain and those more distant. The thermally induced components in this motion resemble an immense respiration—inward and upslope during the day, downslope and outward at night—which is reflected in characteristic diurnal variations in the weather. The wind shifts from night to day, and humidity, cloudiness, rainfall frequency, and turbidity tend to increase toward afternoon with the influx of air from lower elevations.

Thus, a typical day at the Observatory may dawn bright and clear. Visibility is excellent. Peaks on other islands 80 miles distant and more are distinguishable without difficulty. The trade inversion lies several thousand feet below, and trapped beneath it are the clouds and the bulk of the water vapor, dust, and haze. In the clear atmosphere insolation is intense—frequently over 1.70 cal. cm.$^{-2}$ min.$^{-1}$ at true solar noon—and the temperature of the black lava and of the air rises rapidly.

By early afternoon, moister air appears to be seeping upward along the mountain. The humidity increases and fractocumuli advance up the slopes. In the next hours the Observatory may be briefly enveloped in fog or light rain; but by evening the clouds have dissipated and the conditions which opened the day return. Nights are generally clear. Of course, individual days may vary widely from this regime.

The role of the trade inversion in this process is not completely understood. Almost unquestionably it may impede, but does not necessarily prevent, vertical transport of air along the slopes; so that on Mauna Loa, as on mountains elsewhere, the local circulation dominates the diurnal aspects of climate.

Through turbulent exchange, mountains tend also to take on the properties of the surrounding free air. This is more pronounced at summits (because of their greater exposure) than on the slopes and for seasonal than for diurnal factors.

Thus the climate at the Observatory reflects the influences of the mountain circulation, the free air, the continentality of Mauna Loa's own great bulk and surface area, and the tropical maritime surroundings. The data which follow combine the year-long record at the Observatory with the temperature, humidity, and rainfall for

TABLE 1.—*Temperature (° F.) at or near Mauna Loa Observatory*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Highest of record	62	63	60	65	68	70	70	69	67	68	64	67
Mean maximum	48.4	46.6	49.3	53.6	55.8	58.8	56.7	56.6	57.8	56.5	53.0	49.6
Mean minimum	29.6	28.9	31.3	33.7	34.5	37.1	35.6	36.6	36.7	36.6	33.3	31.9
Lowest of record	22	20	20	25	24	24	26	29	29	29	23	22
Mean daily range	18.8	17.7	18.0	19.9	21.3	21.7	21.1	20.0	21.1	19.9	19.7	17.7
Years of record	6	5	4	6	6	6	6	5	5	5	5	5

several earlier years at two nearby stations, first at 11,500 feet and later at 10,958 feet.

Temperature.—The mean monthly maximum and minimum temperatures, the mean daily range, the highest and lowest observed, and the years of record are given in table 1. Although a detailed commentary cannot be undertaken here, the moderateness, even of the extremes, is noteworthy. The rapid rise of temperature in the spring, its more gradual decline in autumn, and the early maximum with a second peak in late summer, are all predominantly marine and free air in character. The diurnal range, on the other hand—large for the altitude and the oceanic Tropics—is attributable to the great expanse of the upper mountain and to the radiative properties of its dark lavas.

Rainfall.—The chief year-round source of rainfall in the Hawaiian Islands is orographic uplift of the moist trade wind. During the cooler season, and in the absence of the trade, this is complemented by rainfall associated with frontal passages and cyclonic circulations, including the so-called Kona storms, and in the island interiors and uplands by convective showers.

Observations made over a 4-year period at or near the Observatory are summarized in table 2A.

The mean annual rainfall of approximately 25 inches appears to be consistent with extrapolations from island-wide isohyetal charts based on longer periods of record, but using only gages below about 6,000 feet.

The record is much too short to justify reading a seasonal trend into it, but the intimation of a double maximum is at least not incompatible with the cyclonic rainfall contribution of winter and the greater frequency during the summer of local convective showers on the upper mountain. The wettest month of record was January 1956 with 12.89 inches. The variability of rainfall is suggested by the fact that in 1958 the same month had only a trace.

The indication in table 2B of a maximum frequency in late afternoon presumably reflects again the formation of showers within the ascending mountain currents, and is in contrast with the nocturnal maximum characteristic of a marine climate and found at lower elevations in regions exposed to the trades.

Wind.—Continuous observations of wind at the Observatory site date only from July 1957, but appear to confirm others made during short intervals over the preceding years. On the whole, speeds are moderate, and no obvious topographic accelerations have been evident. Strongest winds of the year were the sustained speeds of 75 m.p.h. with gusts to 100 experienced in March 1958. This was not, however, a local condition, but a time of high wind generally, due to an unusual situation—the proximity of a tropical storm. Again in January 1959 a similar event occurred, this time producing average winds of 80 m.p.h. with gusts exceeding 105.

Table 3 shows for January and July 1958 the average hourly speed and the frequencies of specified directions. July winds, in the mean, slightly exceeded those for January, but evidence of seasonality from so brief a record is questionable. On the other hand, the abrupt turnabout from southerly (downslope) flow at night to the upslope directions (west through north to east) during the day is unmistakable, and—as was mentioned earlier—is in marked contrast with the winds in the nearby free air, which exhibit little diurnal variation. The reversals in air movement, being related to the heating and cooling of the mountain slopes, follow shortly after sunrise and sunset (compare, in this respect, January with July); the lightest wind occurs at the times of the reversals.

Humidity.—With the bulk of water vapor confined by the trade inversion to levels below the Observatory for most of the day, the average absolute humidity is low. The relative humidity displays two noteworthy characteristics: first, a diurnal course quite unlike that commonly observed, in that humidity on many days tends to vary directly, rather than inversely, with temperature (fig. 8); and second, a high frequency of exceptionally low humidities—often below 5 percent for extended periods, and occasionally below 1 percent for most of a day. The first proceeds directly from the invasion of the upper slopes by lower level air during the afternoon. The second is more obscure, being at times almost certainly

TABLE 2.—*Precipitation at Mauna Loa Observatory*

A. Mean Monthly Rainfall		B. Hourly Rainfall, Percentage Frequency (trace or more) of All Observations			
Month	Inches	Hour ending (LST)	%	Hour ending (LST)	%
January	3.9	01	2.0	13	4.9
February	2.1	02	2.6	14	6.6
March	4.0	03	2.0	15	6.1
April	0.7	04	2.0	16	6.4
May	1.2	05	2.3	17	7.5
June	0.3	06	2.6	18	6.4
July	2.0	07	2.6	19	4.0
August	2.9	08	2.9	20	4.0
September	1.9	09	2.3	21	2.6
October	1.2	10	3.2	22	1.7
November	1.5	11	3.5	23	1.7
December	3.4	12	4.0	24	2.3

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TABLE 3.—*Mean hourly winds at Mauna Loa Observatory*

January 1958, Monthly Mean 9.1 m.p.h.

Hour ending (LST)	01	02	03	04	05	06	*07	08	09	10	11	12	13	14	15	16	17	*18	19	20	21	22	23	24
Percentage W through E	19	13	16	13	16	16	16	16	19	71	90	100	100	100	100	100	94	74	61	42	19	16	13	16
Percentage SE through SW	81	87	84	87	84	84	84	84	77	26	10	0	0	0	0	0	6	23	29	58	81	84	87	84
Mean wind speed (m.p.h.)	9.4	9.4	9.6	9.8	10.7	10.3	9.9	9.8	7.0	5.5	7.1	7.6	9.5	10.1	10.2	9.6	8.9	7.6	6.9	8.2	9.2	9.5	10.2	10.6

July 1958, Monthly Mean 9.5 m.p.h.

Hour ending (LST)	01	02	03	04	05	*06	07	08	09	10	11	12	13	14	15	16	17	18	*19	20	21	22	23	24
Percentage W through E	0	0	0	0	0	0	0	39	81	84	94	90	90	97	97	97	100	94	90	48	10	6	6	3
Percentage SE through SW	97	97	97	100	94	100	100	52	19	16	6	10	3	3	3	3	0	6	6	45	81	94	90	97
Mean wind speed (m.p.h.)	11.5	10.6	10.8	10.3	10.5	10.1	9.4	7.1	7.3	8.3	9.4	10.5	11.0	10.8	10.6	9.9	9.4	8.5	7.7	6.4	7.3	9.3	10.2	10.5

*Indicates sunrise and sunset.
Underscore indicates minimum wind speed.
Double underscore indicates maximum wind speed.

due to nocturnal subsidence over the radiatively cooled mountain, but at other times—as when low humidity persists through the day—to the breaking down of the ascending mountain current (perhaps when insolation is weak and the inversion strong), or to marked subsidence within the general air flow around the southern flank of the Pacific High.

Measurements of the total precipitable water above Mauna Loa [16] suggest that the afternoon rise in surface humidity involves only a relatively thin skin of moister air.

Clouds and sunshine.—Visual observations, from which the diurnal and seasonal variations in cloud types and frequencies could be obtained, are available only for a portion of the daylight hours and the single year that the Observatory has been manned. Other useful indices of sky cover are the proportion of possible sunshine received in each daylight hour and the frequency of clear, partially obscured, and overcast skies. Observations of the latter kind are summarized in table 4 for August 1957 through February 1958.

Since even the thinnest and most transparent clouds were included in this tabulation, it considerably understates the sunniness of the site and the frequency with which the solar disc can be seen; and it would appear from these and other data that about 90 percent of the nighttime and well over 50 percent of the daytime hours are nearly or entirely free from cloud above the level of the Observatory.

The afternoon maximum in sky cover is due again primarily to the formation of fractocumuli in air rising along the mountain slopes. Perhaps because of its

TABLE 4.—*Mean hourly sky cover (percentage frequency) at Mauna Loa Observatory*

Hour of observation (LST)	08	09	10	11	12	13	14	15	16	17
Clear skies	59	56	52	47	38	29	21	18	19	24
Half-covered sky or less	74	71	70	66	59	49	37	37	38	46
Overcast	16	14	17	23	20	28	31	35	31	25

smooth terrain and gentle slope, Mauna Loa has fewer orogenic cirrus than do some of the lower but more abrupt mountain barriers of the other islands.

Snow.—Although it has on the average several snowfalls each winter, Mauna Loa does not even then bear a permanent snow mantle. Snow, usually light, also occurs at the Observatory from time to time, but the mean snow line is at about 12,000 feet. With intense insolation and low humidity, evaporation is extremely rapid; yet snow has been found at the summit even in midsummer, tucked away beneath the lava.

Thunder, lightning, hail.—Like other severe weather, these are infrequent and relatively mild at the Observatory. From July 1957 to August 1958 only 5 days had thunderstorms, and on all these occasions hail approximately one-sixteenth inch in diameter was also observed.

"Seeing" and turbidity.—Visiting astronomers [6] have found the "seeing" highly satisfactory, but systematic observations of it, day and night, have not yet been attempted. However, computations of turbidity from solar radiation measurements (q.v.) will soon begin. Scattering in the circumsolar region appears to be minimal.

8. SOME SCIENTIFIC USES

IN THE PAST

In the 2 years since the construction of the Observatory, a number of scientific endeavors have taken advantage of its elevation, the low turbidity and water vapor content of the overlying atmosphere, or some other special attribute of the site. These studies are briefly listed below, with references to published reports wherever possible.

The forms taken by snow crystals growing under natural conditions in an aerosol-free environment, December 1956 to January 1957, Geophysical Research Directorate [9]. With the buildings at 11,150 feet providing a base of operations, microphotographs were taken of freshly fallen snow flakes at the summit of Mauna Loa.

Spectrographic observations of water vapor in the atmosphere of Mars during that planet's close approach in July 1956 and of Jupiter in May 1957, National Geo-

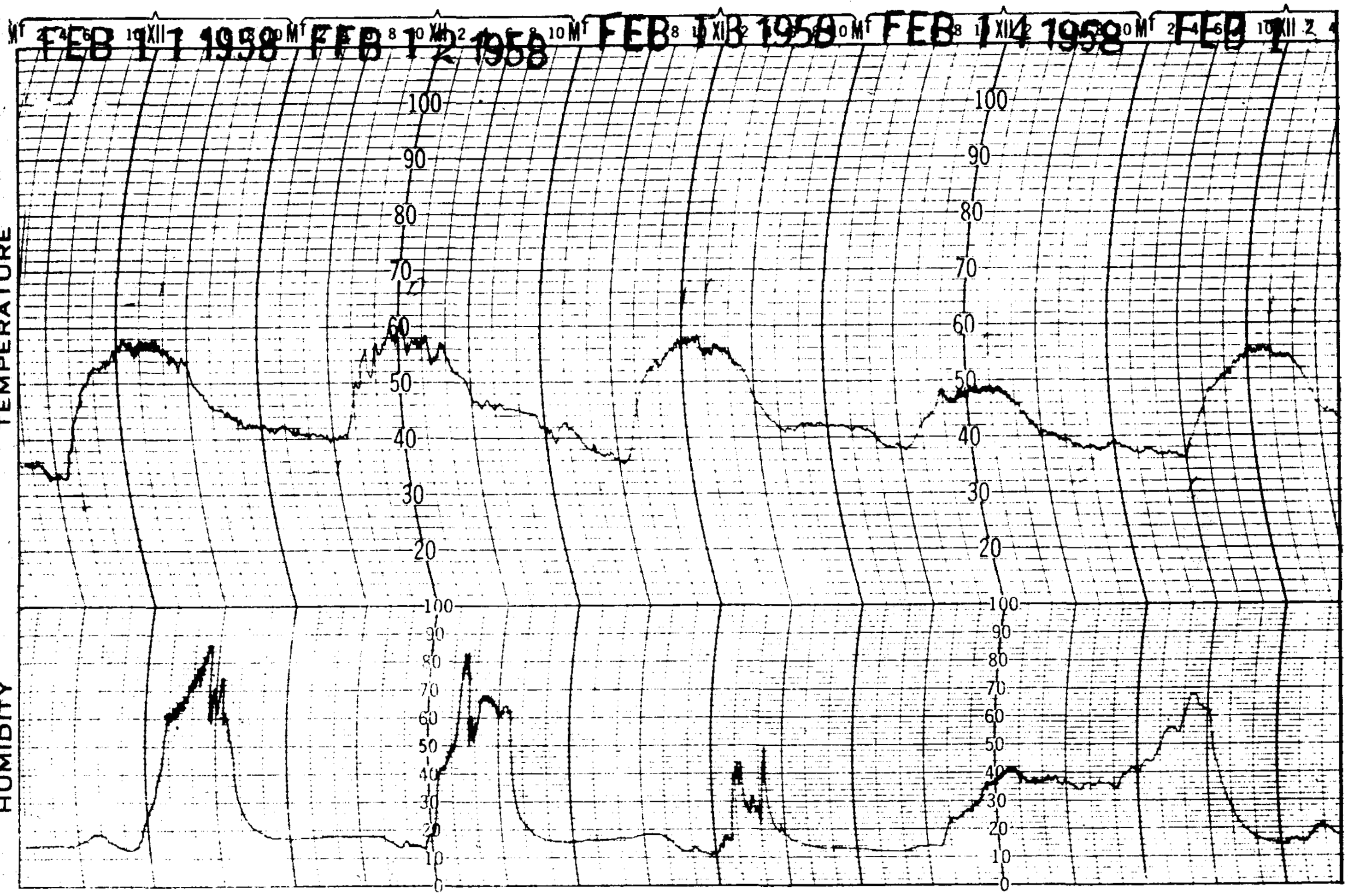

FIGURE 8.—A representative hygrothermograph chart, Mauna Loa Observatory. The tendency for humidity to increase during the afternoon probably reflects the influx of air from lower levels.

graphic Society and National Bureau of Standards [6]. A high-dispersion laboratory-type instrument was used. The prime requisite was a minimum of water vapor in the terrestrial atmosphere.

Spectroradiometry of the sun between 0.3 and 2.5 microns, June 1956 and May 1957, National Bureau of Standards [16]. A lead sulfide cell and a photoemission tube were used in these observations to cover the spectral range. Strong absorption by water vapor in this band required that the superambient atmosphere be as free from it as possible.

Atmospheric transmission in the infrared, July to September 1957, Naval Research Laboratory [19]. Light from two 5-foot carbon-arc searchlights mounted at about 10,000 feet on the facing (south) slope of Mauna Kea was analyzed by an infrared spectrometer at the Observatory, 17 miles distant. This project utilized the long optical path through the clear air above the inversion offered by the facing sister peaks (fig. 2).

Lunar occultation program, October 1957, Army Map Service. Precision timing of stellar occultations by a photo-multiplier operating off a 12-inch reflecting telescope was used to connect the Hawaiian Islands with the North American geodetic datum.

PRESENT PROGRAMS

Present observations at Mauna Loa are of three kinds: local weather; continuation of the International Geophysical Year (IGY) programs in atmospheric composition, solar radiation, and particulate matter; and others for special purposes. Pertinent meteorological observations and synoptic analyses are made also at Hilo and Honolulu.[2]

Routine meteorological observations and analyses.—At the Observatory, local weather is recorded hourly between 0600 and 1700 LST and autographic tracings are obtained of the atmospheric pressure, temperature, relative humidity, wind speed and direction, precipitation, and duration of sunshine. Time-lapse cloud photography is used routinely to preserve the visual aspect of the weather.

These observations serve not only the usual meteorological and climatological purposes, but by describing the local state of the atmosphere they provide the correlative information needed to validate and interpret data from the IGY and other programs. An example of this is the present attempt by the authors to account for the diurnal

[2] Programs in geomagnetism, solar flares, and cosmic rays begun during the IGY are in progress elsewhere in the Hawaiian Islands, including the 10,000-foot summit of Haleakala, Maui, by the University of Hawaii and other organizations.

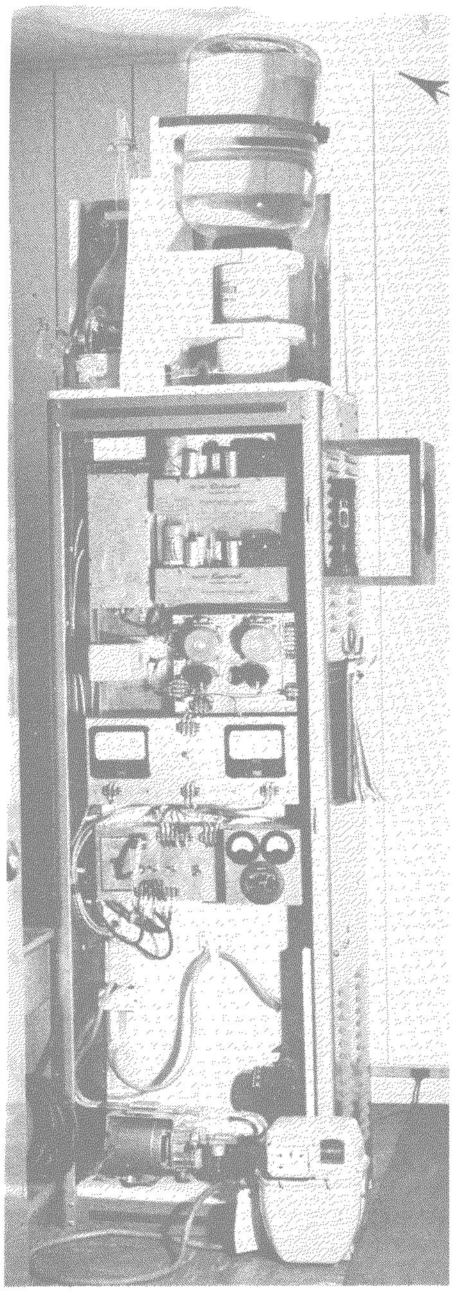

FIGURE 9.—Regener automatic surface ozone recorder. Arrow points to glass tubing from air intake mounted 3 feet above the Observatory roof.

variation in surface ozone at Mauna Loa in terms of the mountain circulation.

Further correlative information is provided by the Weather Bureau's aerological station at Hilo where upper-air soundings of temperature, humidity, and wind, often to altitudes of 30 km., are made twice daily (at 0200 and 1400 LST, four times daily on IGY World Days), and by the extensive analysis and forecasting program of the Honolulu Weather Bureau Airport Station, 210 miles to the northwest, which prepares synoptic charts of the broadscale circulation of the atmosphere at sea level (4 times daily) and at 700, 500, and 300 mb. (twice daily)

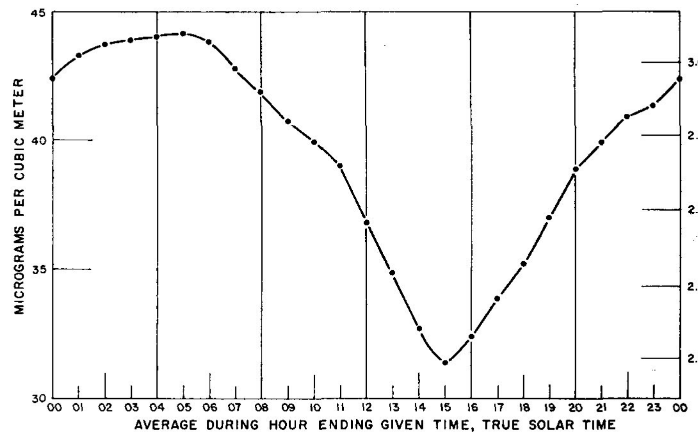

FIGURE 10.—Diurnal variation of surface ozone, November 1957. The afternoon minimum may be due to the influx of lower-level air whose ozone content has been depleted by contact with vegetation or aerosol-bearing water droplets.

over an area which extends from the western United States, through the northern and equatorial Pacific Ocean, to eastern Asia.

The IGY observations.—The meteorological programs initiated at Mauna Loa during the IGY are being conducted in accordance with the appropriate instruction manuals, and these should be referred to for further procedural details concerning them [15]. Instruments, procedures, and a few preliminary results will be touched on briefly in what follows and, wherever possible, references will be cited for the less familiar observations.

Surface ozone.—Continuous recordings of surface ozone have been made since August 1957 by means of automatic chemical sampling equipment recently developed by Regener [14]. The procedure, which is absolute and highly specific for ozone, utilizes the differential oxidation of potassium iodide to iodine within two air streams, one of them heated to 300° C. to dissociate its ozone. Sodium thiosulphate is used to prevent volatilization of the iodine. The resolving time of the instrument is approximately one minute.

A preliminary study of the first 14 months of record indicates that the variations in surface ozone at Mauna Loa are related to both local and large-scale features of the atmospheric circulation. A marked seasonality is evident, with a spring maximum and autumn minimum like that found elsewhere in surface and total ozone. Monthly means ranged from 33 micrograms per cubic meter in October 1957 to 68 micrograms per cubic meter in April 1958, the rise being especially steep from late winter to early spring. The lowest mean hourly value observed was about 20 and the highest near 100 micrograms per cubic meter; the lowest and highest 1-minute values were approximately 7 and 135 micrograms per cubic meter, respectively.

Superimposed upon these seasonal trends, and often of comparable amplitude, is a pronounced diurnal variation with early morning maxima (a secondary peak is common shortly after sunrise) and minima during midafternoon (fig. 10). This is attributed to the local circulation of up- and down-slope winds generated by the radiational heating and cooling of the mountain itself, the afternoon minimum being more specifically ascribed to the influx from below of air whose ozone content has been depleted during its ascent by contact with vegetation, water droplets, or aerosols in the moist subinversion layer (below about 6,500 feet).

Striking variations in the amount of surface ozone have also been observed to accompany changes in the broad circulation patterns in the Pacific area. Thus, during February 1958 ozone increased abruptly with the transition from the prevailing trade wind regime to a strong westerly flow around deep cyclones centered some distance north of the Hawaiian Islands, and decreased again with the return of the trades. A report on these observations is in preparation.

Total ozone.—The Observatory's Dobson Spectrophotometer (No. 63), by which the total depth of atmospheric ozone is determined from the differential absorption by ozone of two spectral lines in the ultraviolet portion of the solar beam, was put into operation on November 27, 1957. Its elevation (it is the highest permanent installation of its kind), the clarity of the overlying atmosphere, and the relatively small ozone variations typical of the latitude are expected to make its observations valuable not only for their contribution to the synoptic ozone program, but also for calibration purposes—principally the determination of the extra-terrestrial constants. The Mauna Loa spectrophotometer is to be used as a standard for the United States Dobson network.

Lunar observations from 3 days before to 3 days after full moon are also being made, and these will be compared with those in the Antarctic where changes in the moon's angular elevation are too small for close calibration of the instrument.

On the basis of the first 10 months of record, day-to-day variations in total ozone at Mauna Loa appear to be small, but the amounts themselves and the amplitude of the seasonal variation, which ranged from approximately .250 cm. in February to .288 cm. in May 1958 (the Vigroux absorption coefficients were used in these computations) are high for the latitude [13]. However, these values and the late occurrence of the seasonal peak relative to that in middle and high latitudes must await the confirmation of additional observations.

Carbon dioxide.—As part of the worldwide effort begun during the IGY to obtain baseline measurements suitable for defining the present CO_2 content of the atmosphere and thus detect secular trends, this component is being continuously recorded at Mauna Loa Observatory by means of a Model 70 Infrared Gas Analyzer (fig. 11), an instrument specifically designed for the monitoring of flowing gas samples [1].

The analyzer operates by measuring the energy loss of an infrared beam traversing a gas sample. Radiation from an infrared source, after being mechanically chopped at 20 c.p.s., passes through the test-gas-filled cell, where its absorption produces a cyclic pressure pulsation. This is transmitted to the tantalum diaphragm of a condenser microphone and thence converted to a voltage which is recorded. A reference gas of known CO_2 content is used as a standard. Air intakes are mounted on four 20-foot towers 450 to 500 feet distant and in mutually perpendicular directions from the main Observatory buildings. Two upwind flows are sampled concurrently, any difference between them being interpreted as due to local contamination.

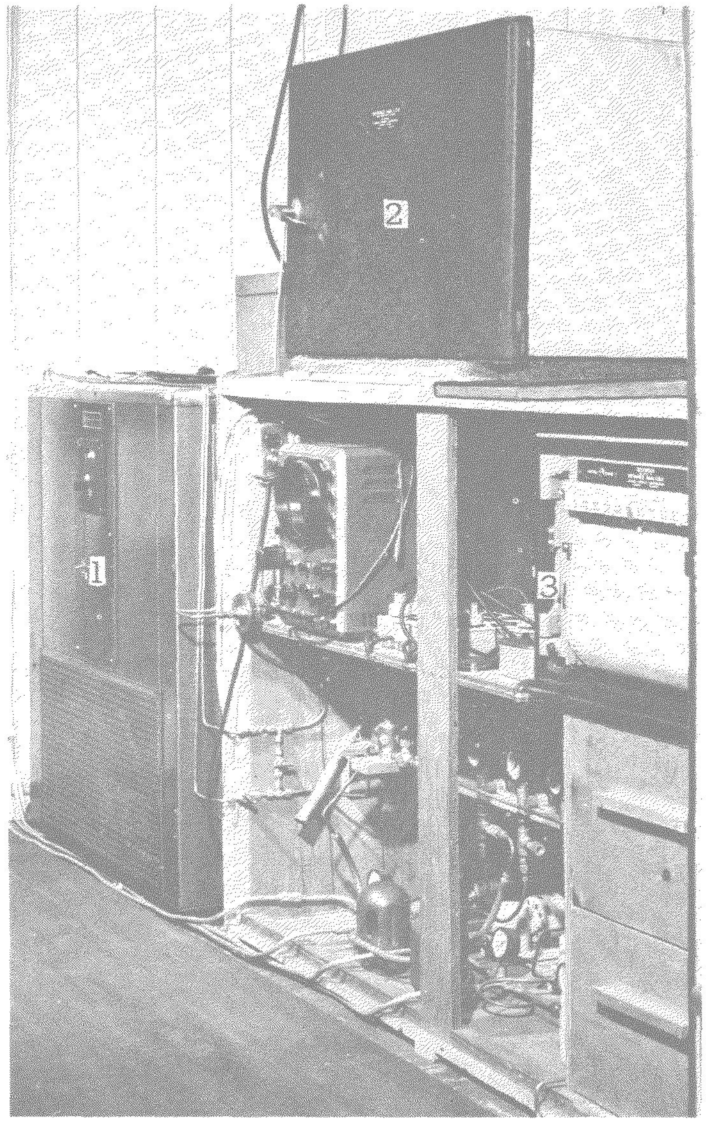

FIGURE 11.—Infrared analyzer for CO_2. (1) freezer to remove water vapor which would otherwise interfere with the analysis, (2) analyzer box, (3) recorder.

Data secured at Mauna Loa since sampling began in March 1958 are sufficiently similar to those obtained elsewhere to support previous indications that in the absence of local pollution the carbon dioxide concentration in the lower atmosphere is substantially uniform over the earth.

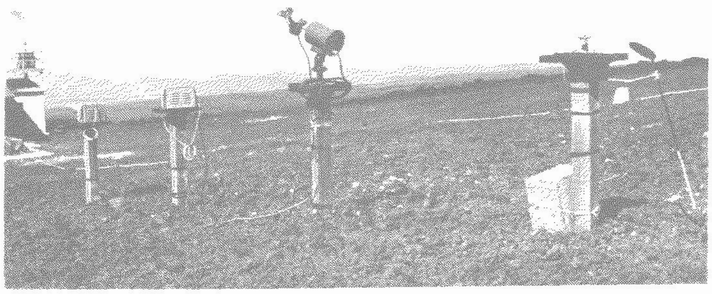

FIGURE 12.—Solar radiation instruments, facing northeast. From left to right, Beckman and Whitley (Gier and Dunkle) total hemispherical and net exchange radiometers, and Eppley normal incidence and horizontal incidence pyrheliometers. Notice the loose, rough texture of the ground.

The Observatory data also suggest a diurnal variation, perhaps related again to the mountain circulation, and a seasonal trend, with mean monthly values decreasing gradually from approximately 314 p.p.m. (parts per million) in May to 312 p.p.m. in August.

Solar radiation.—The solar radiation measurements made at Mauna Loa since November 1957 are part of an international program designed to increase our knowledge of the radiation fluxes to and from the earth's surface, and hence of the earth's heat balance and budget. The instruments being employed for this purpose at Mauna Loa are shown in figure 12. They include the Eppley (10-junction) horizontal incidence pyrheliometer (pyranometer) for the total incoming (short wave) radiation from sun and sky; the Eppley normal incidence pyrheliometer, for direct solar radiation (solar intensity), equatorially mounted and driven by a synchronous motor to follow the sun; the Beckman and Whitley (Gier and Dunkle) total hemispherical radiometer for the total (long wave, terrestrial) radiation from earth and atmosphere; and the Beckman and Whitley net exchange radiometer for the net transfer of (long wave) radiation between earth and atmosphere ([15 Part VI], [5]). All are continuously recording.

Filters (Nos. OG1, RG2, and RG8) for subdividing the spectral regions are to be used with the normal incidence pyrheliometer, thus—among other things—permitting the turbidity coefficients to be computed.

Fission products.—The use of the radioactive products of nuclear tests as tracer materials for studying the atmospheric circulation has been described by Machta [8]. As one of the network of fallout stations, Mauna Loa has operated, since August 1957, a small (40 c.f.m.) air filtration system in which a week's run constitutes a single sample. Filters are sent for analysis to the Naval Research Laboratory, Washington, D.C.

Freezing nuclei.—The Bigg-Warner expansion chamber

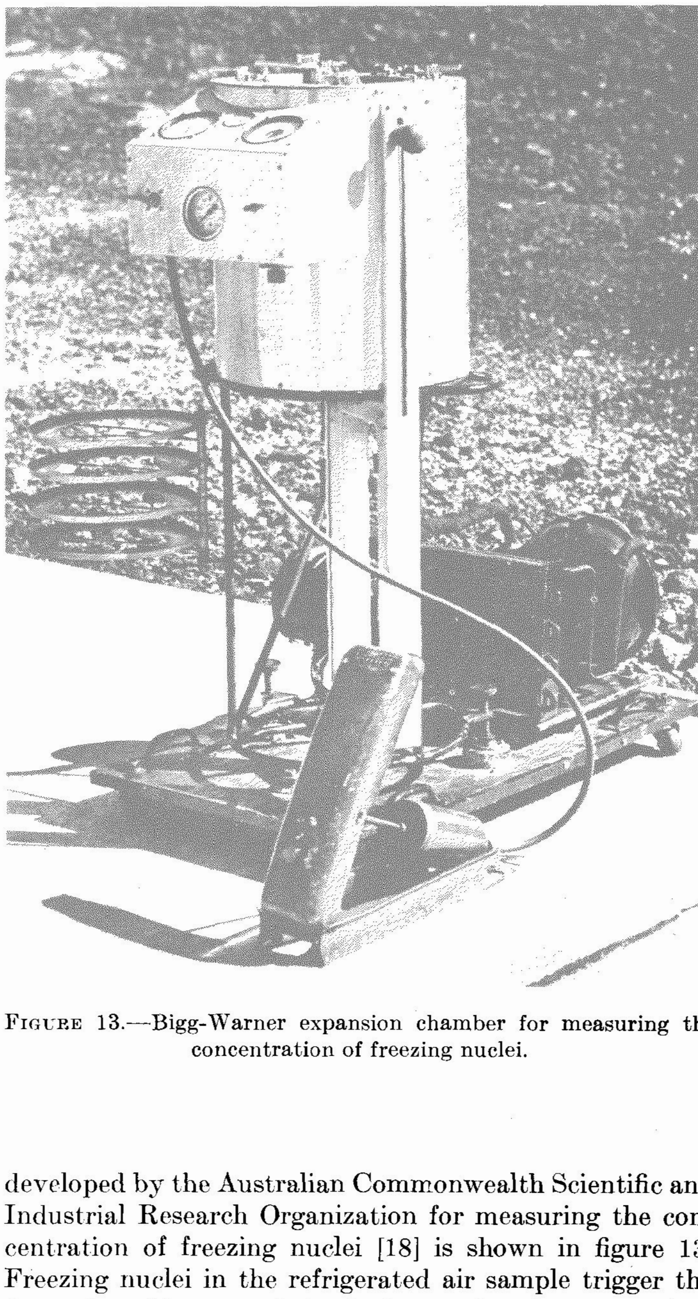

FIGURE 13.—Bigg-Warner expansion chamber for measuring the concentration of freezing nuclei.

developed by the Australian Commonwealth Scientific and Industrial Research Organization for measuring the concentration of freezing nuclei [18] is shown in figure 13. Freezing nuclei in the refrigerated air sample trigger the formation of ice crystals in the fog produced on expansion. These crystals fall into a dish of slightly supercooled sugar solution at the bottom of the 10-liter tank, where they enlarge rapidly and may be readily counted by inspection. By varying the initial overpressure to which the air sample is subjected, a spectrum of the freezing nuclei population as a function of temperature may be obtained.

Daily counts made at the Observatory since December 1957 show preliminary evidence of occasional peaks occurring within a few days of those observed elsewhere. A current hypothesis in the field relates anomalous freezing nuclei activity to meteor showers a month earlier and to singularities in rainfall, cirrus cloudiness, and other geophysical phenomena. The Mauna Loa data are included in a recent summary by Kline and Brier [7] of these apparent correlations.

Micrometeorites.—The scavenging of cosmic dust from large volumes of air pumped through fibreglass filters began at Mauna Loa in August 1957 at the request of the Swedish oceanographer, Hans Pettersson, who saw in the deposition rate of micrometeoritic materials on the earth's surface a possible means of dating the oceanic sediments [10]. After a weekly 24-hour run, the filters are analyzed for iron, nickel, and cobalt in the II Chemisches Institut der Universität, Vienna. Nickel, believed far in excess of any possible contamination from terrestrial sources, has been found in most of the filters from Mauna Loa [11].

FOR THE FUTURE

The year since the assignment of a permanent staff to the Observatory has been occupied largely with the installation, calibration, and maintenance of the scientific equipment and, more recently, with the reduction of data for forwarding to IGY collection centers. Because of their value virtually all the IGY programs at Mauna Loa have been continued beyond the official termination of the International Geophysical Year in December 1958.

As the instrumental and observational aspects of the work settle into routine, a limited amount of time is also becoming available for a preliminary study and interpretation of the record and, on a modest scale, for additional investigations which reflect the personal interests of the staff.

Mountain circulation and climate.—The motions and properties of the lower 1,000 feet of Mauna Loa's atmospheric envelope, and the structure and role in the mountain circulation of the trade inversion contiguous to the slopes, are to be explored—at first by wiresonde profiles and soundings of temperature, humidity, and wind, and later by more elaborate means. In addition to their intrinsic interest and their pertinence to an evaluation of the local factors in Mauna Loa's weather and climate, it is hoped that these observations may permit the exchange coefficients within the mountain's envelope and between it and the surrounding air to be computed.

Atmospheric interrelationships.—The ready accessibility at the Observatory of the weather records on the one hand (local, upper air, synoptic charts) and the IGY observations on the other (ozone, carbon dioxide, solar radiation) makes it a convenient place in which to study the interrelationships between them; that is, the meteorological correlates of diurnal, seasonal, and synoptic variations in ozone, carbon dioxide, and radiation, and conversely, the possibility of anticipating synoptic developments—for example, the formation and motion of Kona storms—through precursory variations in, say, total ozone.

Others.—Among other projects now in prospect for Mauna Loa are observations of the vertical gradients of ozone (by ozonesonde) and carbon dioxide (by flask sampling and aircraft traverses) along the mountain slopes and in the nearby free air. More accurate determinations of surface humidity and of the total precipitable water in the overlying atmosphere await the receipt of stable infrared hygrometers. The local and synoptic concomitants of the exceptionally low humidities commented upon earlier are also to be looked into. The freedom of the site from the pollution almost invariably present in continental air masses makes it well suited to baseline observations of atmospheric electricity, and measurements of conductivity, potential gradient, and ionization rate are being planned.

These and other proposed studies must, of course, be contingent on the availability of suitable instruments and on prior obligations to the IGY and other present programs.

9. CONCLUSION

The elevation and accessibility of the Mauna Loa Observatory, the comfort in which high-altitude work can be done throughout the year, its insularity, and its isolation during the night and much of the day from a large part of the tropospheric water vapor and turbidity, are advantageous for many observations within and outside the atmosphere. It is especially suited for those which require exceptional transparency of the air, and has already been utilized in a number of such projects.

The usefulness of the Observatory, particularly for the determination of standard or baseline values of, and secular trends in, solar radiation, the atmospheric constituents, and for other observations is further enhanced by its geographical isolation. Scarcely the slightest prospect exists that within the foreseeable future the site can deteriorate significantly through the encroachment of cities or industry upon the present highly stable population and specialized agricultural economy.

A good paved road and, less immediately, commercial electric power remain the Observatory's most pressing needs. However, increasing recognition that the present site at 11,150 feet and the summit 2,500 feet above are potentially among the world's most valuable terrestrial platforms, leaves little doubt that these improvements will be made.

Present research at Mauna Loa centers about the IGY observational programs and on studies of the mountain climate and circulation, but additional work in several fields is planned.

Within its limitations of time, space, and personnel, the staff is prepared to offer housing and its other facilities to visiting scientists and to assist in the instrument-reading-and-servicing aspects of projects established there. Organizations and individuals desiring further information about the Observatory or the use of its facilities are invited to address their inquiries to the Director of Meteorological Research, U.S. Weather Bureau, Washington 25, D.C., or to the authors.

ACKNOWLEDGMENTS

The Mauna Loa Observatory owes its existence principally to Robert H. Simpson who, as Meteorologist-in-

Charge of the Weather Bureau's Pacific Supervisory Office, Honolulu, and afterwards, endeavored constantly to bring it into being; to his successors at Honolulu, Gordon D. Cartwright and Roy L. Fox, who dedicated much time and effort to the same end; to Ralph Stair of the National Bureau of Standards for his and his agency's cooperation in the construction of the present buildings; to Dr. Harry Wexler, Director of the Office of Meteorological Research of the Weather Bureau for his unstinting support and encouragement; and to the devoted work of the staffs of the Weather Bureau Airport Station, Hilo, and the Pacific Supervisory Office, Honolulu.

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